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The Information-Seeking Behavior of Engineers

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THE INFORMATION-SEEKING BEHAVIOR OF ENGINEERS

Introduction

Engineers are an extraordinarily diverse group of professionals, but an attribute common to all engineers is their use of information. Engineering can be conceptualized as an information processing system that must deal with work-related uncertainty through patterns of technical communications. Throughout the process, data, information, and tacit knowledge (see Note 1) are being acquired, produced, transferred, and utilized. The fact that these data, information, and tacit knowledge deal with hard technologies or may be "physically or hardware encoded" (*1*) should not detract from the observation that engineering is fundamentally an information processing activity. The engineer can be viewed as the center of that information xrocessing system. According to Sayer (*2*, p. 25),

> Engineering is a production system in which data, information, and knowledge are new materials. Whatever the purpose of the engineering effort, the engineer is an information processor who is constantly faced with the problem of effectively acquiring, using, producing, and transferring data, information, and knowledge.

While acknowledging that other models exist (see *3* for a discussion of other models), we have chosen to view the information-seeking behavior of engineers within a conceptual framework of the engineer as an information processor. This article uses the chosen framework to discuss information-seeking behavior of engineers, reviewing selected literature and empirical studies from library and information science, management, communications, and sociology. The article concludes by proposing a research agenda designed to extend our current, limited knowledge of the way engineers process information.

Background

Stevens (*4*) and Paisley (*5*) provide useful discussions of information in terms of history, definitions, and frameworks for analysis. The concept of information-seeking is imbedded in studies of users, use, and uses. These studies constitute "one of the most extensive and amorphous areas of research in library and information sciences over the better part of four decades" (*6*). (See the *Annual Review of Information Science and Technology* for reviews of information needs and use). The majority of the studies, and certainly the early studies, concentrated on the uses of scientific and technical information (STI). In the majority of these STI usage studies however, scientists, not engineers, were the subjects of investigation.

The literature regarding the information-seeking behavior of engineers is fragmented and superficial. The results of these studies have not accumulated to form a significant body of knowledge. The difficulty in applying the results of these studies has been attributed to the lack of a unifying theory, standardized methodology, and common definitions. With specific reference to engineers, the difficulty may be attributed to the failure of researchers to take into account the essential difference between science and technology and, similarly, between engineers and scientists (7, p. 4). This fundamental difference is emphasized by Vincenti (*8*) in his analysis of the role of knowledge in technological developments.

Engineering is a process dominated by engineers and technology as opposed to scientists and science. As Joenk points out, this fact "leads to different philosophies, habits, and behaviors not only about contributing to the technical literature but also to using the technical literature and other sources of information" (*9*, p. 348). Recent interest in the information-seeking behavior of engineers corresponds to rising interest and concerns regarding industrial competitiveness and technological innovation. Consequently, an understanding of the information-seeking behavior of engineers is essential to predicting information use and to planning, developing, and implementing engineering information systems. Such an understanding is also critical to enhancing economic competitiveness, improving productivity, and maximizing the process of technological innovation.

The World of Engineering

According to the U.S. Bureau of Labor Statistics, engineers held almost 1,411,000 jobs in 1988. About half of these jobs were located in manufacturing industries; about 511,000 were located in nonmanufacturing industries; and about 185,000 were employed by federal, state, and local governments. About one-third of these jobs (439,000) were held by electrical engineers followed, in decreasing order of frequency, by mechanical (225,000), civil (186,000), and industrial (132,000) engineers. A bachelor's degree in engineering from an accredited engineering program is generally acceptable for beginning engineering jobs. Most engineering degrees are granted in branches such as electrical, chemical, or nuclear engineering. Within these branches, most engineers specialize; more than 25 major specialties are recognized by professional societies. *The Occupational Outlook Handbook* (*10*) lists and discusses the ten branches of engineering: aerospace; chemical; civil; electrical and electronics; industrial; mechanical; metallurgical, ceramic, and materials; mining; nuclear; and petroleum.

Formal registration is a requirement in the United States for engineers whose work may affect life, health, or property, or who offer their services to the public. Registration generally requires, in addition to a degree from an engineering program accredited by the Accreditation Board for Engineering and Technology (ABET), four years of relevant work experience and satisfactory performance on a state examination.

The engineering profession cannot be described fully without reference to the nature of engineering work, knowledge, and communication. These three areas are also important in establishing the conceptual framework of the engineer as an information processor.

ENGINEERING WORK

What is engineering work like? What tasks and activities are performed by engineers on a day-to-day basis? Florman (*11*), an engineer who has written extensively on the nature of the professional, proclaims that "the essence of engineering lies in its need and willingness to embrace opposites. Empiricism and theory, craftsmanship and science, workshop and laboratory, apprenticeship and formal schooling, private initiative, and government venture, commerce and independent professionalism, military necessity and civic benefit—all of these and more have their place" (*11*, p. 64). In trying to sort out the diversity of engineering, Adams notes that it may be categorized according to, among other things, particular industries, fields, disciplines, job functions, and end products. He concludes that engineering is interlocked with science, mathematics, and business in a complex environment that "requires a multidimensional map for understanding" (*12*, p. 38).

The characteristic activity of engineers is making things. Expressed more formally, engineering is usually defined as the application of scientific knowledge to the creation or improvement of technology for human use (*13*, p. 3). The term "technology" as used in the context of describing engineering work encompasses products,

systems, structures, and processes. Engineering work is often described as a process that originates with the first idea for a new or improved technology that is put into use. The National Research Council, for example, describes what it calls "the product realization process" as extending "over all phases of product development from initial planning to customer follow-up" (*14*, p. 17). Phases in this process include: definition of customer needs and product performance requirements, planning for product evolution, planning for design and manufacturing, product design, manufacturing process design, and production.

Engineering work can also be described in terms of the kinds of tasks and activities that engineers perform on a day-to-day basis. Because of the multidimensional nature of engineering work and the extensiveness of the product development process, engineers perform a wide variety of tasks. Engineering work involves cognitive activities and physical tasks that include the technical and the nontechnical, the routine and the creative, the rational and the serendipitous. According to Ritti (*15*), engineering work consists of scientific experimentation, mathematical analysis, design and drafting, building and testing of prototypes, technical writing, marketing, and project management. Murotake calls attention to the nontechnical elements of engineering work: "the process of engineering work is not only a technical one, but a social one in which management, communication, and motivation influence the efficiency, quality, and innovativeness of the project team's work" (*16*, p. 20). If the characteristic physical activity of engineering is making things, the characteristic cognitive activity is problem-solving. Laudan notes that "change and progress in technology is achieved by the selection and solution of technological problems, followed by choice between rival solutions" (*17*, p. 84).

The great variety in the nature of the tasks and activities that comprise engineering work is often reflected in the individual engineer's work, as well. Kemper notes that the typical engineer is likely to define problems, come up with new ideas, produce designs, solve problems, manage the work of others, produce reports, perform calculations, and conduct experiments (*13*, p. 2). Hollister also describes the work of an engineer as multifaceted: "He begins with an idea, a mental conception. He conducts studies, and when necessary, research into the feasibility of this idea. He directs the building and operation of what he has planned" (*18*, p. 18). Mailloux highlights the centrality of knowledge production and transfer to engineering work. She reports that about "20% of an engineer's time is spent in the intellectual activities of engineering—conceiving, sketching, calculating, and evaluating—with the remaining 80% spent on activities associated with creating, accessing, reviewing, manipulating, or transferring information" (*19*, p. 239).

Although engineers perform many tasks independently, most products result from team effort, requiring engineers to share their knowledge and the result of their work with others (*20*, p. 156). For complex products, teamwork is required at each stage of the engineering process. The literature on concurrent engineering indicates that teamwork is a natural requirement of the need to integrate the various stages of the engineering process (see, e.g., *21*, p. 86). Bringing a high-quality product to market in an efficient manner often requires, for example, that design engineers communicate with managers, manufacturing and marketing staff within their firm as well as with people outside their organizations, such as clients, funders, and suppliers.

Engineering work takes place in a variety of environments, depending not only on the nature of the product being developed and the stage of product development, but also on the type of employing organization. Organizations employing engineers include universities, research centers, government laboratories and agencies, and private sector manufacturers and consulting firms. The basic goal of engineering is to produce usable products in the shortest possible time at the lowest possible cost. This goal drives the work and communication activities of virtually all engineers, but it is manifested to a different degree in different employment settings.

ENGINEERING KNOWLEDGE

What kinds of knowledge do engineers need to perform the tasks and activities described above? How is knowledge acquired? Engineering work and knowledge are so closely intertwined, that it is difficult to discuss one without the other. As noted by Vincenti, "...engineering knowledge cannot—and should not—be separated from engineering practice. The nature of engineering knowledge, the process of its generation, and the engineering activity it serves form an inseparable whole" (*8*, p. 257). Engineering practice, in other words, involves both knowing and doing. Even the popular literature suggests the wide variety of knowledge needed by engineers, due to the diversity of their work:

> [The engineer's] task is not alone that of contrivance with material things, for which he must possess an extensive working knowledge of scientific principles and facts. He must also thoroughly understand the functions to be performed by the projected work when it is completed, the methods of its manufacture and construction, and the economics that govern its use. He must have an understanding of the crafts that are to be used and of the organization of the work. It is his responsibility to coordinate and guide the contributions of labor, machines, money, and ideas, and to exert the control necessary to attain his objectives within the prescribed limits of time, cost, and safety. (*18*, p. 18)

Scholarly literature on the nature and generation of engineering knowledge reinforces such popular accounts. Donovan asserts that the range of scientific and technical knowledge used by engineers includes "not only the more formal types of experimental and theoretical knowledge but also all forms of practical skill and tacit understanding as well..." (*22*, p. 678).

Schön rejects the model of technical rationality which is typically applied to scientific and technical professions and paints instead a different picture of engineering knowledge. He argues that the situations encountered by practicing professionals are increasingly characterized by "complexity, uncertainty, instability, uniqueness, and value conflicts" (*23*, p. 14); such situations require intuitive, artistic, and ethical responses in addition to purely technical and rational ones. Schön labels this model of professional work "tacit knowing-in-action" (*23*, p. 49) and describes the development of a new process to produce a desired gunmetal color to illustrate his argument. He represents the activities of the mechanical engineers involved in this project as "a reflective conversation with the materials of the situation...[that] wove its way through stages of diagnosis, experiment, pilot process, and production design" (*23*, p. 175). Throughout this process, experiments are used to explore puzzling

phenomena, test the applicability of potentially useful theories, or achieve particular technological effects. These experiments, however, often produce unanticipated phenomena and outcomes, which then trigger new hypotheses, questions, and goals (*23*, p. 177). Schön's analysis of this and other examples suggests that the knowledge required to reach a technological solution is derived from the integration of intuition, past experience, creativity (often in the form of analogy development), theory, experimentation, and reflective thinking that occur in a particular problematic situation. He also argues that engineering solutions incorporate social and ethical considerations.

As these accounts suggest, the notion of tacit knowledge permeates discussions of engineering work. Tacit knowledge is knowledge that cannot be articulated. Polanyi describes tacit knowledge—part experience, part intuition, part tactile sensation—as combining "knowing what" and "knowing how" and declares that it is expressed in such actions as expert diagnoses, the performance of skills, and the use of tools (*24*, pp. 6–7). Another important type of engineering knowledge, visual information, is also expressed in a nonverbal manner. The importance of visual information in technological work is the subject of a paper by Ferguson and is also discussed by Breton (*25*). Layton (*26*) describes this phenomenon, too: "technologists display a plastic, geometrical, and to some extent nonverbal mode of thought that has more in common with that of artists than that of philosophers" (*26*, p. 37). The importance of these two nonverbal modes of thought is rooted in the essence of engineering as the production of physically encoded knowledge. Engineers must know how to make things, and the results of this knowledge are, first and foremost, encoded in the technologies produced. Engineers rely heavily on nontextual information, such as interpersonal communication, drawings, and the examination of physical objects, to acquire the knowledge they need to perform their work.

Holmfeld found three common mechanisms for generating needed knowledge in engineering work. Engineers rely on the "cut and try" method to refine and fine tune (*20*, p. 129). They also frequently search their memories for familiar concepts and designs in order to increase their confidence in some new variation (*20*, pp. 134-135). Finally, they make use of that scientific knowledge which they deem to be relevant and readily applicable. This knowledge is often in the form of a simple fact, such as the optimum hole size or speed rotation, resulting from scientific work (*20*, p. 148). A number of other writers also note that engineers adopt, at times, the methods used by scientists to generate knowledge. Florman describes engineering work as encompassing both theory and empiricism (*11*, p. 64). Ziman writes that "technological development itself has become 'scientific': it is no longer satisfactory, in the design of a new automobile, say, to rely on rule of thumb, cut and fit, or simple trial and error. Data are collected, phenomena are observed, hypotheses are proposed, and theories are tested in the true spirit of the hypothetico-deductive method" (*27*, p. 130).

Constant presents a detailed history of the origin of the modern jet engine, a revolutionary technological advance. He presents a "variation-retention" model of technological change that is based on the process of random variation and selective retention that occurs in biological organisms. Technological conjecture, which can occur as a result of knowledge gained from either scientific theory or engineering practice, yields potential variations to existing technologies. These variations are

subsequently tested, and successful variations are retained (*28*, pp. 6–7). In the case of the turbojet revolution, technological conjecture was based on engineers' knowledge of scientific theories. The design, development, and testing oı systems that resulted in the retention of the most successful variation involved, on the other hand, the technical and craft knowledge needed to carry out those tasks.

Vincenti traces five "normal" (as opposed to revolutionary) developments in the history of aerospace engineering to detail what he calls "the anatomy of engineering design knowledge" (*8*, p. 9). His examples reveal that technological developments require a range of scientific, technical and practical knowledge as well as information about social, economic, military, and environmental issues. Vincenti conducts three important analyses of engineering knowledge. The first involves his own elaboration of the variation-selection model of the growth of technological knowledge. Vincenti concludes, after examining numerous examples from history, that the mechanisms for producing variations in engineering design include three types of cognitive activities (*8*, p. 246): searching past experience to find knowledge that has proved useful, including the identification of variations that have not worked; incorporating novel features thought to have some chance of working; and "winnowing" the conceived variations to choose those most likely to work. Vincenti notes that these activities occur in an interactive and disorderly fashion. Selection occurs through physical trials such as everyday use, experiments, simulations (e.g., the use of wind tunnels), or analytical tests such as the production of sketches of proposed designs, calculations, and other means of imagining the outcome of selecting a proposed variation (*8*, pp. 247–248).

Vincenti also proposes a schema for engineering knowledge that categorizes knowledge as either descriptive (factual knowledge), prescriptive (knowledge of the desired end), or tacit (knowledge that cannot be expressed in words or pictures but is embodied in judgment and skills). Descriptive and prescriptive knowledge are explicit; tacit knowledge is implicit. Both tacit and prescriptive knowledge are procedural and reflect a "knowing how" (*8*, pp. 197–198). Finally, Vincenti enumerates and defines specific engineering knowledge categories: fundamental design concepts, criteria and specifications, theoretical tools (i.e., mathematical methods and theories and intellectual concepts), quantitative data, practical considerations, and design instrumentalities (i.e., procedural knowledge and judgmental skills) (*8*, pp. 208–222). He then presents a matrix that details how each type of knowledge is acquired. The possible sources of engineering knowledge that he describes include transfer from science or generation by engineers during invention, theoretical and experimental engineering research, design practice, production, or direct trial and operation (*8*, p. 235).

Communications and management studies confirm the findings of historical and sociological research about the range of knowledge, information, and data needed in engineering work. Ancona and Caldwell investigated the tasks and communication of new product development teams in high technology companies. The authors note that such teams "are responsible not only for the specific technical design of a product, but also for coordinating the numerous functional areas and hierarchical levels that have information and resources necessary to make the new product a success" (*29*, p. 174). Ancona and Caldwell found that new product teams progress through three phases of activity: creation, development, and diffusion. The communication- and information-

intensive tasks that accompany these phases include (*29*, pp. 184–185):

- Getting to know and trust team members
- Determining the availability of resources
- Understanding what other functional groups think the product can/should be
- Investigating technologies for building the product
- Exploring potential markets
- Solving technical problems
- Coordinating the teams' work internally and externally
- Keeping external groups informed
- Building relationships with external groups that will receive the team's output
- Promoting the product with manufacturing, marketing, and service groups.

Ancona and Caldwell conclude that information systems designed to support these changing activities must be flexible and support the team's need to identify and contact relevant external groups, generate and evaluate ideas, and coordinate work. Barczak and Wilemon also look at the communication patterns of new product development teams and find a similar range of communication purposes: to discuss product features, technical issues, customer needs, manufacturing issues, schedules and timing, financial issues, managerial issues, and resources issues (*30*, pp. 101–109).

THE ENGINEERING COMMUNITY

Engineering work and communication are rooted in the concept of "community." A community is a group of people who maintain social contact with each other and who exhibit common interests, goals, norms of behavior, and knowledge. As members of a profession, engineers share a common knowledge base and set of espoused values. The profession prescribes its own approach to work behavior. Engineering is also a social activity; most work is accomplished as a result of group effort and requires extensive interpersonal communication.

Studies of scientific communities look at the values, norms, knowledge, methods, reward system, and culture shared by community members and frequently underscore the role of interpersonal communication in defining the community and holding it together (see, e.g., *31–33*). This type of investigation has not often been performed in relation to engineering communities. Gaston notes that "[the problem of the internal workings of the technological community] is virtually unexplored. . . . In contrast to the sociology of the scientific community, little is known about the sociology of the technological community" (*34*, p. 495). Constant also notes the lack of research on technological communities. He writes that "While extensive research has been done on 'invisible colleges,' research fronts, and the community structure of science, there has been little analogous [sic] sociological or historical investigation of technological practice" (*35*, p. 8). Rothstein, pointing to the diversity inherent in engineering, warns that defining the entire profession of engineering as a single community provides a model that is inadequate to describe engineering behavior. He argues that the huge variety of occupations and disciplines in engineering demonstrates that there is no such thing as a single engineering community. Further, he contends that most discussions of professional communities fail to direct enough attention to the nature

of professional knowledge and its influence on behavior. He contends that the heterogeneity, rate of change, and degree of specialization of engineering knowledge also lead to the emergence of specific communities in engineering (*36*, pp. 73–97).

Some work has begun to explore the extent to which members of engineering communities share similar work tasks, goals, and methods; are governed by shared social and technical norms; and engage in extensive informal information exchange among themselves. Laudan finds justification for this approach in that "cognitive change in technology is the result of the purposeful problem-solving activities of members of relatively small communities of practitioners, just as cognitive change in science is the product of the problem-solving activities of the members of scientific communities" (*17*, p. 3). Layton also contends that "...the ideas of technologists cannot be understood in isolation; they must be seen in the context of a community of technologists..." (*27*, p. 41). Donovan notes that "the study of engineering knowledge must not be divorced from the social context of engineering" and suggests that "the interplay of social values and theoretical understanding in the evolution of scientific disciplines certainly has its analogues in engineering, although the values and knowledge involved are often quite different" (*22*, p. 678).

Rosenthal discusses the design-manufacturing team in new product development. He says that such teams represent "a community of interest" with a shared commitment to the group effort. The group shares information and advice, as well as instructions and decisions (*37*, p. 45). He describes the difficulties in merging these two subcommunities or cultures, because design and manufacturing engineers have developed their own "tacit understandings built up through years of working on particular problems with special points of view" (*37*, p. 44).

The notion of an engineering community has also been addressed in connection with aerospace work. Vincenti describes informal communities of practitioners as the most important source of knowledge generation and means of knowledge transfer in aerospace. He defines a community as those involved in work on a particular aerospace development or problem (e.g., fasteners, airfoils, or propellers). Vincenti attributes several functions to these engineering communities. Competition between members supplies motivation, while cooperation provides mutual support. The exchange of knowledge and experience generates further knowledge, which is disseminated by word of mouth, publication, and teaching and is also incorporated into the tradition of practice. The community also plays a significant role in providing recognition and reward. Vincenti describes the particular roles of important types of aerospace engineering institutions, such as government research organizations, university departments, aircraft manufacturers, military services, airlines, professional societies, government regulatory agencies, and equipment and component suppliers" (*8*, pp. 238–240). He concludes, however, that "formal institutions do a complex multitude of things that promote and channel the generation of engineering knowledge. They do not, however, constitute the locus for that generation in the crucial way that informal communities do. Their role...is to supply support and resources for such communities" (*8*, p. 240).

Constant also describes aerospace communities as the central locus of technological cognition. He notes that the aeronautical community is, in fact, composed of a multilevel, overlapping hierarchy of subcommunities and he argues that technological

change is better studied at the community as opposed to the individual, firm, national, or industry level. Constant describes the community as the embodiment of traditions of practice (*28*, p. 10):

> [Technological traditions of practice] define an accepted mode of technical operation, the conventional system of accomplishing a specified technical task. Such traditions encompass aspects of relevant scientific theory, engineering design formulae, accepted procedures and methods, specialized instrumentation, and, often, elements of ideological rationale. A tradition of technological practice is proximately tautological with the community which embodies it; each serves to define the other. Traditions of practice are passed on in the preparation of aspirants to community membership. A technological tradition of practice has, at minimum, a *knowledge dimension, including both software and hardware, and a sociological* dimension, including both social structure and behavioral norms.

Constant discusses further the importance of community norms in engineering. He alleges that, at least in connection with complex systems, there are "fundamental social norms governing the behavior of technological practitioners which are very close in structure, spirit, and effect to the norms governing the behavior of scientists" (*28*, p. 21). Such norms guide the development of techniques and instruments and the reporting of data. Constant also argues for the existence of "counternorms" in engineering that are similar to those attributed to scientists by Mitroff (*38*). Constant explains that "Technological practitioners are required to be objective, emotionally neutral, rational, and honest. Yet technological practitioners often are—and protagonists of technological revolution usually are—passionate, determined, and irrationally recalcitrant in the face of unpleasant counter evidence bearing on their pet ideas" (*28*, p. 24).

These descriptions of the world of engineering indicate that the activities performed by engineers are diverse and multifaceted. Engineering is defined as the creation or inprovement of technology; as such, it clearly encompasses both intellectual and physical tasks, i.e., both knowing and doing. Engineering work is fundamentally both a social and a technical activity. It is a social activity in that it often involves teamwork, as individuals are required to coordinate and integrate their work. It is also a social activity in that the production of the final product depends on the ability to maintain successful social relationships (e.g., negotiate with vendors, maintain smooth personal relations among members of a work group).

The nature of engineering work suggests that engineers require access to a variety of tools and information resources. Further, the use of these tools and resources and the way they are integrated into engineering work may be planned in some cases and ad hoc in other situations. The engineering community, although it has received little attention from researchers, clearly plays an important role in the conduct of engineering work and the generation and transfer of engineering knowledge, information, and data. From this depiction of the engineering profession, we now move to the establishment of a broader conceptual framework for our model of engineers as information processors.

Toward a Conceptual Framework for Investigating the Information Behavior of Engineers

Engineers are not scientists. Arguments that a scientist is a more generic term merely implies that the two are one and the same. They are not. The practice of lumping the two groups [engineers and scientists] together is self-defeating in information behavior studies because confusion over the characteristics of the sample has led to conflicting results and to a greater difficulty in developing normative measures for planning, developing, and implementing information systems and policy in either science or technology.

Further, the terms "engineer" and "scientist" are not synonymous. Although the previous section has made it clear that many engineers—especially in high tech branches such as aerospace—perform a variety of empirical and theoretical tasks, the differences in work environment and personal/professional goals between the engineer and scientist prove to be an important factor in determining their information-seeking behavior. The following sections explore the science/technology and scientist/engineer dichotomy.

THE NATURE OF SCIENCE AND TECHNOLOGY

The relationship between science and technology is often expressed as a continuous process or normal progression from basic research (science) through applied research (technology) to development (utilization). This relationship, which is illustrated in Figure 1, is based on the widely held assumption that technology grows out of or is dependent upon science for its development. This "assumed" relationship is the foundation upon which U.S. science policy is based and may help to explain the use of the conventional phrase "scientists and engineers."

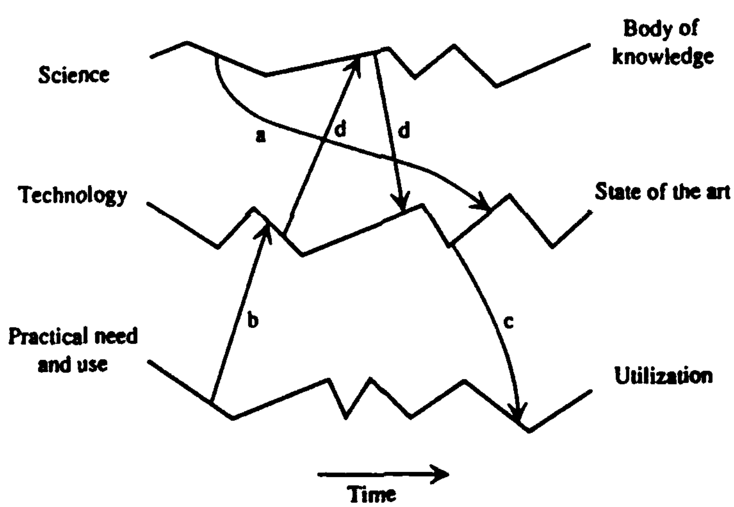

FIGURE 1. *The progression from science through technology to development as a continuous process.*

However, the belief that technological change is somehow based on scientific advance has been challenged in recent years. Technological change has been increasingly seen as the adaption of existing technological concepts in response to demand (*41*). Moreover, several years of study that attempted to trace the flow of information from science to technology have produced little empirical evidence to support the relationship (*40*, *41*). Price, for example, claims (*42*, p. 563)

> The naive picture of technology as applied science simply will not fit the facts. Inventions do not hang like fruits on a scientific tree. In those parts of the history of technology where one feels some confidence, it is quite apparent that most technological advances are derived immediately from those that precede them.

The single-tree concept, shown in Figure 2, is often used to illustrate the relationship between science and technology as a continuous process. Shapley and Roy argue that such a metaphor is historically inaccurate. In their case for a reorientation of American science policy, they argue that the two-tree concept, which is shown in Figure 3, is a more accurate metaphor and is much more useful in developing science policy (*42*, pp. 19–20).

Shapley and Roy contend that a normal progression from science to technology does not exist, nor is there direct communication between science and technology (*43*, pp. 19–20). Allen's 1977 study of transfer of technology and the dissemination of technological information in R&D organizations found little evidence to support the relationship between science and technology as a continuous relationship. Allen concludes that the relationship between science and technology, which is depicted in Figure 4, is best described as a series of interac.ions that are based on need rather than on a normal pro‿ression (*44*, p. 55).

According to Allen (*44*), (a) the results of science do progress to technology in the sense that some sciences such as physics are more closely connected to technologies

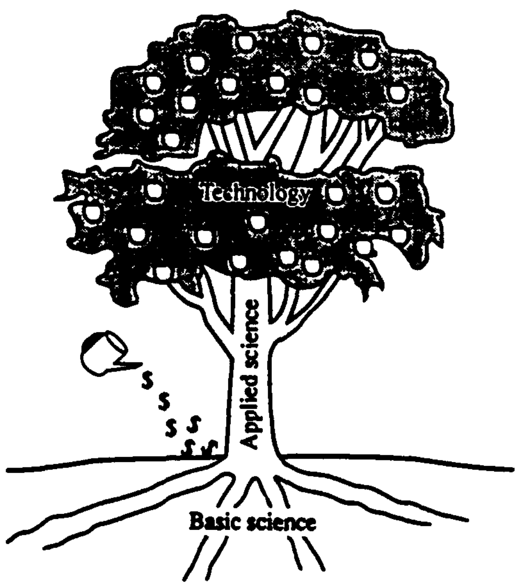

FIGURE 2. *Science and technology as a single tree*

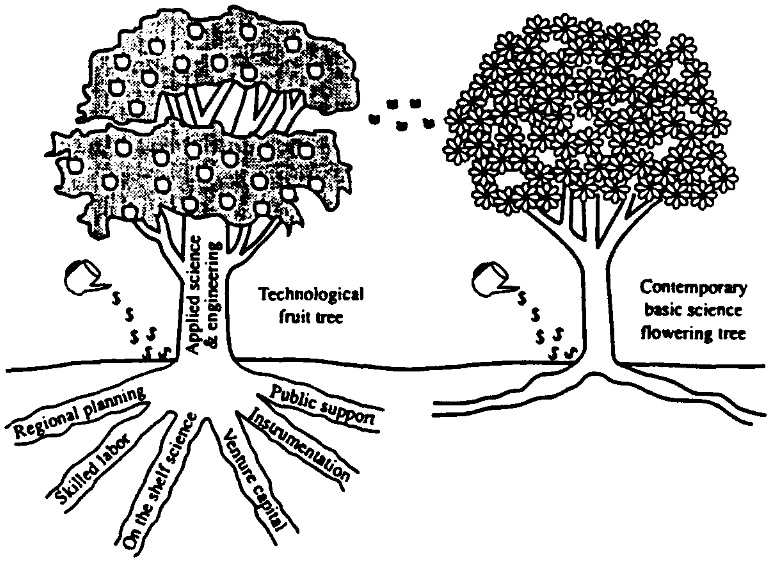

FIGURE 3. *Technology and science as separate trees.*

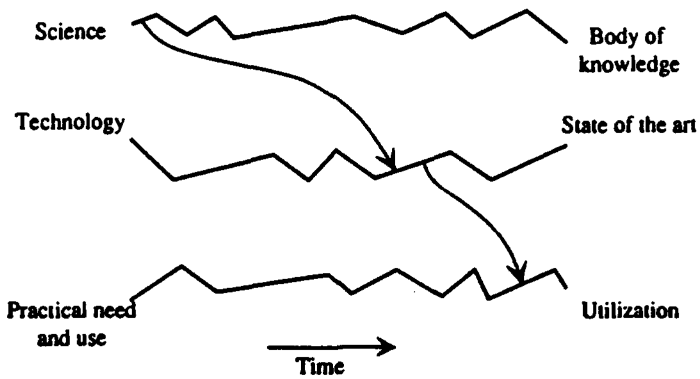

FIGURE 4. *The progression from science through technology to development as a series of interactions.*

such as electronics, but (b) overall a wide variation exists between science and technology. The need for a (c) device, technique, or scientific understanding influences technology. Technology, in turn, (d) responds to a need and, in doing so, may generate the need for an understanding of certain physical phenomena (*44*, pp. 55–56). A direct communication system between science and technology does not exist to the extent that communication between science and technology is restricted almost completely to that which takes place through the process of education.

Price concludes that science and technology progress independently of one another. Technology builds upon its own prior developments and advances in a manner independent of any link with the current scientific frontier and often without any necessity for an understanding of the basic science underlying it (*42*, p. 554).

In summarizing the differences between science and technology, Price makes the following 12 points. (1) Science has a cumulating, close-knit structure; that is, new

knowledge seems to flow from highly related and rather recent pieces of old knowledge, as displayed in the literature. (2) This property is what distinguishes science from technology and from humanistic scholarship. (3) This property accounts for many known social phenomena in science and also for its surefootedness and high rate of exponential growth. (4) Technology shares with science the same high growth rate, but it shows quite complementary social phenomena, particularly in its attitude to the literature. (5) Technology therefore may have a similar, cumulating, close-knit structure to that of science, but the structure is of the state of the art rather than of the literature. (6) Science and technology each therefore have their own separate cumulating structures. (7) A direct flow from the research front of science to that of technology, or vice versa, occurs only in special and traumatic cases since the structures are separate. (8) It is probable that research-front technology is strongly related only to that part of scientific knowledge that has been passed down as part of ambient learning and education, not to research-front science. (9) Research-front science is similarly related only to the ambient technological knowledge of the previous generation of students, not to the research front of the technological state of the art and its innovation. (10) This reciprocal relation between science and technology, involving the research front of one and the accrued archive of the other, is nevertheless sufficient to keep the two in phase in their separate growths within each otherwise independent cumulation. (11) It is naive to regard technology as applied science or clinical practice as applied medical science. (12) Because of this, one should be aware of any claims that particular scientific research is needed for particular technological breakthroughs, and vice versa. Both cumulations can only be supported for their own separate ends (*42*, pp. 557–563).

Allen states that the independent nature of science and technology (S&T) and the different functions performed by engineers and scientists directly influence the flow of information in science and technology (*44*, p. 3). Science and technology are ardent consumers of information. Engineers and scientists both require large quantities of information to perform their work. At this level, there is a strong similarity between the information input needs of engineers and scientists. However, the difference between engineers and scientists in terms of information processing becomes apparent upon examination of their outputs.

Information processing in S&T is depicted in Figure 5 in the form of an input-output model (*44*, p. 4). Scientists use information to produce information. From a system standpoint, the input and output, which are both verbal, are compatible. The output from one stage is in a form required for the next stage. Engineers use information to produce some physical change in the world. Engineers consume information, transform it, and produce a product that is information bearing; however, the information is no longer in verbal form. Whereas scientists consume and produce information in the form of human language, engineers transform information from a verbal (or often visual or tacit) format to a physically encoded form. Verbal information is produced only as a byproduct to document the hardware and other physical products produced.

According to Allen, there is an inherent compatibility between the inputs and outputs of the information-processing system of science. He further states that since both are in a verbal format, the output of one stage is in the format required for the

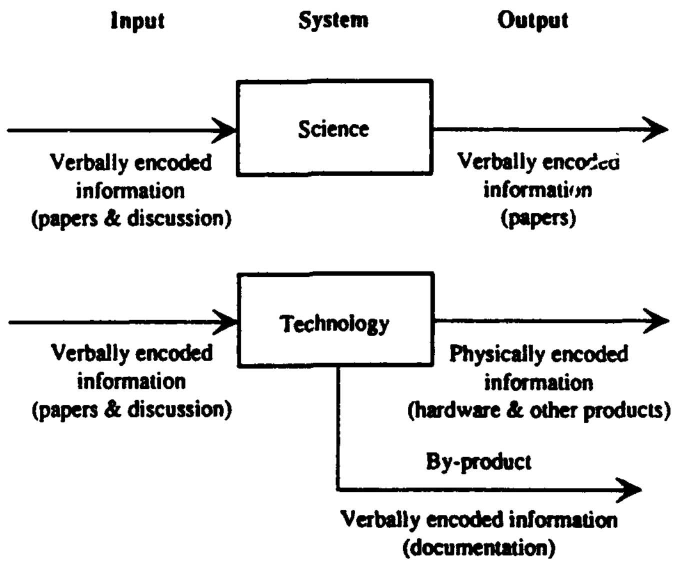

FIGURE 5. *Information processing in science and technology.*

next stage (*44*, p. 3). The problem of supplying information to the scientist becomes a matter of collecting and organizing these outputs and making them accessible. Since science operates for the most part on the premise of free and open access to information, the problem of collecting outputs is made easier.

In technology, however, there is an inherent incompatibility between inputs and outputs. Since outputs are usually in a form different from inputs, they usually cannot serve as inputs for the next stage. Further, the outputs are usually in two parts, one physically encoded and the other verbally encoded. The verbally encoded part usually cannot serve as input for the next stage because it is a byproduct of the process and is itself incomplete. Those unacquainted with the development of the hardware or physical product therefore require some human intervention to supplement and interpret the information contained in the documentation. Since technology operates to a large extent on the premise of restricted access to information, the problem of collecting the documentation and obtaining the necessary human intervention becomes difficult.

DISTINGUISHING ENGINEERS FROM SCIENTISTS

Engineers and scientists exhibit important differences other than the evident differences in education (degree), technical discipline, and type of work/activity. They share such common psychological needs as survival, security, self-esteem, self-expression, belonging, opportunity for growth, and self-determination. The strength of these needs varies from person to person and fluctuates over time. In a collective sense, engineers and scientists share the following attitudes that are conducive to high productivity (*45*, p. 50):

- effective communication
- optimum salary band benefits
- freedom and authority
- optimum utilization

There are also differences that tend to create sharp distinctions between the two groups. At the risk of inviting a charge of "overgeneralization," Peake offers the following list of differences (*45*, p. 52):

Most engineers	Most scientists
Do development, design or applications work	Do research, basic or applied
Apply scientific knowledge	Seek new knowledge
Have engineering degree	Have science degree
Recognize managerial authority	Respect "colleague" authority
Want assignments to good, challenging projects	Want freedom to select their own projects
Like a company with a good record of engineering accomplishment	Like a company with a reputation for scientific advancement
Are hardware oriented	Are software oriented
Dislike preparing talks and publications	Insist on freedom to publish their work
are company oriented (i.e., committed to a variety of work areas, tasks, positions)	Are career oriented (i.e., committed to limited kinds of work areas, tasks, positions)
Dislike ambiguous, uncertain situations	Can work effectively with ambiguity, uncertainty
Are interested in processes, results, realizations	Are interested in concepts, meanings, abstractions
Believe in equalitarian group practices	Believe in authoritarian group practices
Expect to be faced with work schedules, deadlines, constrained resources	Abhor schedules, believe schedules should be self-determined, desire autonomy

Danielson investigated engineers and scientists in an attempt to identify those characteristics that affect their motivation and utilization. He concluded that there are recognizable differences between the two groups. He concluded that engineers and scientists are fundamentally different in terms of how they approach their job, the type and amount of supervision required, the type of recognition desired, the personality traits exhibited, and the differences in their goals (*46*, p. 11).

In their study of the values and career orientation of engineering and science undergraduate students, Krulee and Nadler found that engineering and science students have certain aspirations in common: to better themselves and to achieve a higher socioeconomic status than that of their parents. They report that science

students place a higher value on independence and on learning for its own sake, while engineering students are more concerned with success and professional preparation. Many engineering students expect their families to be more important than their careers as a source of satisfaction, but the reverse pattern is more typical for science students (*47*, pp. 157–158).

Krulee and Nadler also determined that engineering students are less concerned than science students with what one does in a given position and more concerned with the certainty of the rewards to be obtained. They report that, overall, engineering students place less emphasis on independence, career satisfaction, and the inherent interest their specialty holds for them and place more value on success, family life, and avoiding a low-level job. Engineering students appear to be prepared to sacrifice some of their independence and opportunities for innovation in order to realize their primary objectives. Engineering students are more willing to accept positions that will involve them in complex organizational responsibilities and they assume that success in such positions will depend upon practical knowledge, administrative ability, and human relations skills (*47*, pp. 149–151).

In his study of engineers in industry, Ritti found marked contrast between the work goals of engineers and scientists. Ritti draws the following three conclusions from his study: (1) the goals of engineers in industry are very much in line with meeting schedules, developing products that will be successful in the marketplace, and helping the company expand its activities; (2) while both engineers and scientists desire career development or advancement, for the engineer advancement is tied to activities within the organization, while advancement for the scientist is dependent upon the reputation established outside of the organization; and (3) while publication of results and professional autonomy are clearly valued goals of the Ph.D. scientist, they are clearly the least valued goals of the baccalaureate engineer (*15*, p. 5).

Allen states that the type of person who is attracted to a career in engineering is fundamentally different from the type of person who pursues a career as a scientist. He writes that "perhaps the single most important difference between the two is the level of education. Engineers are generally educated to the baccalaureate level; some have a master's degree while some have no college degree. The research scientist is usually assumed to have a doctorate. The long, complex process of academic socialization involved in obtaining the Ph.D. is bound to result in persons who differ considerably in their lifeviews." According to Allen, these differences in values and attitudes toward work will almost certainly be reflected in the behavior of the individual, especially in their use and production of information (*5*, pp. 4–5).

According to Blade, engineers and scientists differ in training, values, and methods of thought. Further, Blade states that the following differences exist in their individual creative processes and in their creative products: (1) scientists are concerned with discovering and explaining nature; engineers use and exploit nature; (2) scientists are searching for theories and principles; engineers seek to develop and make things; (3) scientists are seeking a result for its own ends; engineers are engaged in solving a problem for the practical operating results; and (4) scientists create new unities of thought; engineers invent things and solve problems. Blade states that "this is a different order of creativity" (*48*, p. 111).

INFLUENCE ON INFORMATION BEHAVIOR

Communications in engineering and science are fundamentally different. Communication patterns differ because of the fundamental differences between engineering and sciences and because of the social systems associated with the two disciplines. Holmfeld offers the following examples of how the social systems affect the communication behavior of engineers and scientists (*20*, pp. 262–290).

Engineer

- Contribution is [technical] knowledge used to produce end items or products
- New and original knowledge is not a requirement
- Reward is monetary or materialistic and serves as an inducement to continue to make further contributions to technical knowledge
- Seeking rewards that are not part of the social system of technology is quite proper and also encouraged
- The value of technical knowledge lies in its value as a commodity of indirect exchange
- Exchange networks found in the social system of technology are based on end-item products, not knowledge
- Strong norms against free exchange or open access to knowledge with others outside of the organization exist in the social system of technology
- Restriction, security classification, and proprietary claims to knowledge characterize the social system of technology

Scientist

- Contribution is new and original knowledge
- Reward is social approval in the form of professional [collegial] recognition
- Recognition is established through publication and claim of discovery
- A well-developed communication system based on unrestricted access is imperative to recognition and claim of discovery
- Since recognition and priority of discovery are critical, strong norms against any restriction to free and open communication exist in the social system of science
- Seeking rewards that are not part of the social system of science in return for scientific contribution is not considered proper within the social system of science
- Exchange networks commonly referred to as "invisible colleges" exist in the social system of science; in these networks the commodities are knowledge and recognition (*49*, *50*).

Taylor (*51*), who quotes Brinberg (*52*), offers the following characteristics for engineers and scientists: "Unlike scientists, the goal of the engineer is to produce or design a product, process, or system; not to publish and make original contributions to the literature. Engineers, unlike scientists, work within time constraints; they are not interested in theory, source data, and guides to the literature nearly so much as they are in reliable answers to specific questions" (pp. 39–40).

Anthony et al. suggest that engineers may have psychological traits that predispose them to solve problems alone or with the help of colleagues rather than finding answers in the literature. They further state that "engineers like to solve their own problems. They draw on past experiences, use the trial and error method, and ask colleagues known to be efficient and reliable instead of searching or having someone

search the literature for them. They are highly independent and self-reliant without being positively anti-social" (*53*, p. 742).

According to Allen, "engineers read less than scientists, they use literature and libraries less, and seldom use information services which are directly oriented to them. They are more likely to use specific forms of literature such as handbooks, standards, specifications, and technical reports" (*44*, p. 80). What an engineer usually wants, according to Cairns and Compton, is "a specific answer, in terms and format that are intelligible to him—not a collection of documents that he must sift, evaluate, and translate before he can apply them" (*54*, pp. 375–376). Young and Harriott report that "the engineer's search for information seems to be based more on a need for specific problem solving than around a search for general opportunity. When engineers use the library, it is more in a personal-search mode, generally not involving the professional (but nontechnical) librarian" (*55*, p. 24). Young and Harriot conclude by saying that "when engineers need technical information, they usually use the most accessible sources rather than searching for the highest quality sources. These accessible sources are respected colleagues, vendors, a familiar but possibly outdated text, and internal company [technical] reports. He [the engineer] prefers informal information networks to the more formal search of publicly available and cataloged information" (*55*, p. 24).

Major Empirical Studies of Engineering Information Behavior

Studies concerned with the information-seeking behavior of engineers were reviewed by Pinelli (*56*) to further develop the conceptual framework. Table 1 lists those major research studies deemed significant to this topic and which are discussed in this section.

HERNER (*57*)

Herner's work is one of the first "user" studies specifically concerned with "differences" in information-seeking behavior. He reports significant differences in terms of researchers performing "basic and applied" research, researchers performing "academic and industry" type duties, and their information-seeking behavior. Herner states that researchers performing "basic or academic" duties make greater use of formal information channels or sources, depend mainly on the library for their published material, and maintain a significant number of contacts outside of the organization.

Researchers performing "applied or industry" duties make greater use of informal channels or sources, depend on their personal collections of information and colleagues for information, make significantly less use of the library than do their counterparts, and maintain fewer contacts outside of the organization. Applied or industry researchers make substantial use of handbooks, standards, and technical reports. They also read less and do less of their reading in the library than do their counterparts.

TABLE 1

Overview of Engineering Information Behavior Studies

Year	Principal Investigator	Research Method	Population	Sample Frame	Sample Design	Sample Size	Percentage Response Rate (number responding)	Description
1954	Herner (*57*)	Structured interview	All scientific and technical personnel at Johns Hopkins	Unknown	Unknown	600	100	Survey to determine the information-gathering methods of scientific and technical personnel at Johns Hopkins
1970	Rosenbloom and Wolek (*58*)	Self-administered questionnaire	Members of 5 industrial R&D organizations Members of 4 IEEE interest groups	2 430 Unknown	Census Probability	2 430 Unknown	71 (1 735) Unknown (1 034)	Survey to determine how engineers and scientists in industrial research and development organizations acquire STI
1977	Allen (*44*)	Record analysis Self-administered questionnaire	Unknown	Unknown	Unknown	Unknown	Unknown (1 153)	Survey to determine technology transfer and the dissemination of technological information in research and development organizations
1980	Kremer (*57*)	Self-administered questionnaire	All design engineers at one engineering design firm	73	Census	73	82 (60)	Survey to identify and evaluate the information channels used by engineers in a design company
1981	Shuchman (*60*)	Structured interview Self-administered questionnaire	Engineers in 89 R&D and non-R&D organizations	14 797	Probability	3 371	39 (1 315)	Survey to determine information used and production in engineering
1983	Kaufman (*61*)	Self-administered questionnaire	Engineers in six technology-based organizations	147	Census	147	100 (147)	Survey to determine the use of technical information in technical problem solving

ROSENBLOOM AND WOLEK (*58*)

In 1970, Rosenbloom and Wolek published the results of one of the first "large-scale" industry studies that was specifically concerned with the flow of STI within R&D organizations. They report three significant and fundamental differences between engineers and scientists: (1) engineers tend to make substantially greater use of information sources *within* the organization than do scientists; (2) scientists make considerably greater use of the professional (formal) literature than do engineers; and (3) scientists are more likely than engineers to acquire information as a consequence of activities directed toward general competence rather than a specific task.

In terms of interpersonal communication, the engineers in the Rosenbloom and Wolek study recorded a higher incidence of interpersonal communication with people in other parts of their own corporation, whereas scientists recorded a greater incidence of interpersonal communication with individuals employed outside their own corporation. When using the literature, the engineers tended to consult in-house technical reports or trade publications, while the scientists made greater use of the professional (formal) literature.

Rosenbloom and Wolek also report certain similarities between engineers and scientists. The propensity to use alternative types of technical information sources is related to the purposes that will give meaning to the use of that information. Work that has a professional focus draws heavily on sources of information external to the user's organization. Work that has an operational focus seldom draws on external sources, relying heavily on information that is available within the employing organization. Those engineers and scientists engaged in professional work commonly emphasize the simplicity, precision, and analytical or empirical rigor of the information source. Conversely, those engineers and scientists engaged in operational work typically emphasize the value of communication with others who understand and are experienced in the same real context of work.

ALLEN (*44*)

Allen's study of technology transfer and the dissemination of technological information within the R&D organization is the result of a 10-year investigation. Allen describes the study, which began as a "user study," as a systems-level approach to the problem of communication in technology. Many information professionals consider his work to be the seminal research on the flow of technical information within R&D organizations. Allen was among the first to produce evidence supporting different information-seeking behaviors for engineers and scientists. These differences, Allen notes, lead to different philosophies and habits regarding the use of the technical literature and other sources of information by engineers. The most significant of his findings is the relative lack of importance of the technical literature in terms of generating new ideas and in problem definition, the importance of personal contacts and discussions between engineers, the existence of technological "gatekeepers," and the importance of the technical report. Allen states that "the unpublished report is the single most important informal literature source; it is the principal written vehicle for transferring information in technology" (*44*, p. 91).

KREMER *(57)*

Kremer's study was undertaken to gain insight on how technical information flows through formal and informal channels among engineers in a design company. The engineers in her study were not involved in R&D. The reason given most frequently to search for information is problem solving; colleagues within the company are contacted first for needed information, followed by colleagues outside of the company. In terms of the technical literature, handbooks are most important, followed by standards and specifications. Libraries are not important sources of information and are used infrequently by company engineers.

Regardless of age and work experience, design engineers demonstrate a decided preference for internal sources of information. They consult personal files for needed information. The perceived accessibility, ease of use, technical quality, and amount of experience a design engineer has had with an information source strongly influence the selection of an information source. Technological gatekeepers exist among design engineers; they are high technical performers and a high percentage are first line supervisors.

SHUCHMAN *(60)*

Shuchman's study is a broad-based investigation of information transfer in engineering. The respondents represent 14 industries and the following major disciplines: civil, electrical, mechanical, industrial, chemical and environmental, and aeronautical. Seven percent, or 93 respondents, were aeronautical engineers. The engineers, regardless of discipline, display a strong preference for informal sources of information. Further, these engineers rarely find all the information they need for solving technical problems in one source; the major difficulty engineers encounter in finding the information they need to do their job is identifying a specific piece of missing data and then learning who has it.

In terms of information sources and solving technical problems, Shuchman reports that engineers first consult their personal store of technical information, followed in order by informal discussions with colleagues, discussions with supervisors, use of internal technical reports, and contact with a "key" person in the organization who usually knows where the needed information may be located. A small proportion of the engineering profession uses technical libraries and librarians.

In general, Shuchman finds that engineers do not regard information technology as an important adjunct to the process of producing, transferring, and using information. While technological gatekeepers appear to exist across the broad range of engineering disciplines, their function and significance are not uniform; considering the totality of engineering, gatekeepers account for only a small part of the information transfer process.

KAUFMAN *(61)*

Kaufman's study is concerned with the factors relating to the use of technical information by engineers in problem solving. The study reported that, in terms of

information sources, engineers consult their personal collections first, followed by colleagues and then by formal literature sources. In terms of the formal literature sources used for technical problem solving, engineers use technical reports, followed in order by text books, and technical handbooks.

Most sources of information, according to Kaufman, are found primarily through an intentional search of written information, followed by personal knowledge and then by asking someone. The criteria used in selecting all information sources, in descending order of frequency, are accessibility, familiarity or experience, technical quality, relevance, comprehensiveness, ease of use, and expense. Engineers use various information sources for specific purposes. They primarily utilized librarians and information specialists are to find leads to information sources. Engineers used online computer searches primarily to define the problem and technical literature to learn techniques applicable to dealing with the problem. They rely primarily on personal experience to find solutions to the problem.

Kaufman reports that the criteria used in selecting the most useful information sources, in descending order of frequency, are technical quality or reliability, relevance, accessibility, familiarity or experience, comprehensiveness, ease of use, and expense. In terms of the effectiveness, efficiency, and usefulness of the various information sources, personal experience is rated as the most effective in accomplishing the purpose for which it is used; librarians and information specialists receive the lowest rating for efficiency and effectiveness. Most engineers use several different types of information sources in problem solving; however, engineers do depend on their personal experience more often than on any single specific information source.

Engineers as Information Processors

To establish a specific conceptual and organizing framework for further research on information use by engineers, engineering can be viewed as an information processing system that must deal with work-related uncertainty through patterns of technical communications. Throughout the process, data, information, and knowledge are being acquired, produced, transferred, and used. The fact that these data, information, and knowledge may be physically or hardware encoded should not detract from the observation that the process of engineering is fundamentally an information processing activity.

The concept of engineering as an information processing entity represents an extension of the arguments developed by Tushman and Nadler (*62*). The concept has its roots in open systems theory developed by Katz and Kahn (*63*). The major work on organizations and work-related uncertainty can be traced to, among others, Galbraith and Duncan (*64*), who have conceptualized organizations as information processing systems.

Uncertainty, defined as the difference between information possessed and information required to complete a task, is central to the concept of engineering as an information processing activity. Rogers (*65*) states that coping with uncertainty is the central concept in information behavior. The process of engineering is one of

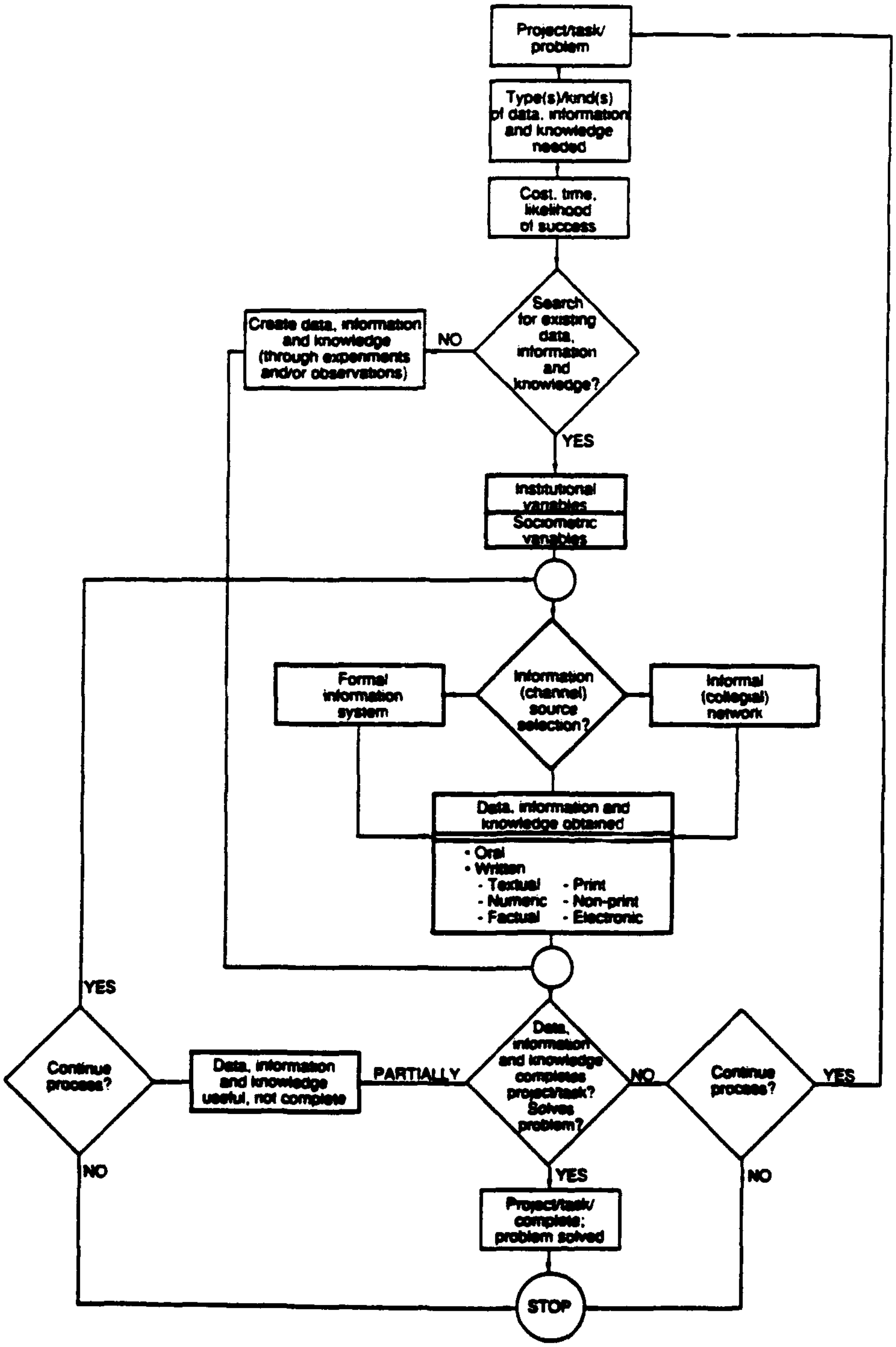

FIGURE 6. *The engineer as an information processor: A structure analysis with data on variables related to information-seeking behavior.*

grappling with the unknown. These unknowns or uncertainties may be technical, economic, or merely the manifestations of personal and social variables. When faced with uncertainty engineers typically seek data, information, and knowledge. In other words, data, information, and knowledge are used by engineers to moderate technical uncertainty. Because engineering always entails coping with a relatively high degree of uncertainty, engineering can certainly be viewed as an informational process. Consequently, information behavior and patterns of technical communication cannot be ignored when studying engineers.

AN ORGANIZING MODEL FOR RESEARCH

The conceptual framework, shown in Figure 6, represents an extension of Orr's scheme of the engineer as an information processor. The framework focuses on information-seeking and assumes that, individual differences notwithstanding, an internal, consistent logic governs the information-seeking behavior of engineers (*66*).

A project, task, or problem that precipitates a need for information is central to the conceptual framework for this research. This need for information may, in turn, be *internally* or *externally* induced and is referred to by Orr as *inputs* or *outputs*, respectively. Orr (*66*), who cites the work of Voight (*67*), Menzel (*68*), Storer (*69*), and Hagstrom (*70*), states that inputs originate within the mind of the individual engineer and include data, information, and knowledge needed to keep up with advanced in one's profession, to perform one's professional duties to interact with peers, colleagues, and coworkers, and to obtain stimulation and feedback from them.

Outputs frequently, but not exclusively, result from an external stimulus or impetus. Outputs serve a variety of functions, including responding to a request for information from a supervisor, a coworker, peer, or colleague; reporting progress; providing advice; reacting to inquiries; defending; advocating; and proposing. Inputs and outputs require the use of specific kinds and types of data, information, and knowledge (*66*, pp. 147–157).

The conceptual framework for this research assumes that, in response to a project, task, or problem, specific kinds or types of data, information, and knowledge are needed. In response to this scenario, engineers are confronted with two basic alternatives: they can create the information through experimentation or observation or they can search the existing information. If they act rationally, the decision to "make or buy" the information will depend upon their subjective perception of the relative likelihood of success in acquiring the desired information by these two alternatives with an acceptable time, and on their perception of the relative cost [money and/or effort] of these alternatives.

If a decision is made to search the existing information, engineers must choose between two information channels. One is the *informal or collegial network*, which is characterized by interpersonal (oral) communications with peers, coworkers, colleagues, gatekeepers, vendors, consultants, "key" personnel, and supervisors and by personal collections of information. The other is the *formal information system*, which includes libraries, technical information centers, librarians and technical information specialists, information products and services, and information storage and retrieval systems. It is assumed that the decision to choose a particular information channel is influenced by institutional and sociometric variables operating within the previously

identified systems. Gerstberger and Allen (*71*), Rosenberg (*72*), and Orr (*66*) theorize that certain sociometric variables influence information source and product selection.

More recent work highlights the value of exploring contextual and situational variables related to information-seeking and use. Taylor's theoretical investigation of information use environments emphasizes the importance of understanding the context in which information is sought, conveyed, and applied. Context for professional groups, including engineers, is defined as a combination of the nature of work problems, solutions, and settings associated with particular types of jobs. Taylor assumes, in other words, that members of a profession share tasks, goals, and needs in a way that influences their use of information. Taylor's analysis recognizes, as Figure 6 shows, that information-seeking and use is determined by the nature of the particular project, task, problem at hand (*73*, pp. 217–255).

A shift in emphasis toward the study of cognitive and situational variables surrounding information-seeking and use, and away from users' personal characteristics and specific systems features, has been advocated by a number of communications and information science researchers, most notably Dervin and Nilan (see *Annual Review of Information Science and Technology*, 21, 1986). They devote special attention to understanding what there is about a particular situation that encourages an individual to use networks in fulfilling an information need. In Figure 6, the subjective perception of cost, time, and likelihood of success may often be situationally driven.

The resulting data, information, and knowledge are evaluated subjectively. The engineer as an information processor faces three possible courses of action. *First*, if the acquired-obtained data, information, and knowledge complete the project or task or solve the problem, the process is terminated. *Second*, if the acquired-obtained, data, information, and knowledge are useful but only partially complete the project or task or solve the problem, a decision is made either to continue the process by reevaluating the information source selection or to terminate the process. *Third*, if the acquired-obtained data, information, and knowledge are not applicable to or do not complete the project or task or solve the problem, a decision is made either to continue the process by redefining the project, task, or problem or to terminate the process.

AN EMPIRICAL STUDY: THE AEROSPACE KNOWLEDGE DIFFUSION RESEARCH PROJECT

We noted earlier that the literature regarding the information-seeking behavior of engineers is fragmented and superficial and that the results have not accumulated to form a significant body of knowledge. The inability to apply these findings is attributable to the lack of a unifying theory, standardized methodology, and common definitions. The simple truth is that little is known about the information-seeking behavior of engineers generally. Further, there is little evidence that addresses differences that may exist among various engineering branches or specialities. We have little knowledge of whether the attributes and information-seeking behaviors associated with engineers in one discipline (e.g., civil) are transferable to engineers in another discipline (e.g., nuclear).

The authors are involved in a research project currently underway that is investigating the production, transfer, and use of federally funded aerospace R&D by aerospace engineers from the perspective of the model presented in Figure 6. This four-phase project is providing descriptive and analytical data regarding the diffusion of aerospace knowledge at the individual, organizational, national, and international levels. It is examining both the channels used to communicate and the social system of the aerospace knowledge diffusion process. Phase 1 investigates the information-seeking behavior of U.S. aerospace engineers and scientists and places particular emphasis on their use of federally funded aerospace R&D and U.S. government technical reports. Phase 2 examines the industry-government interface and places special emphasis on the role of information intermediaries in the aerospace knowledge diffusion process. Phase 3 concerns the academic-government interface and places specific emphasis on the information intermediary-faculty-student relationship. Phase 4 explores the information seeking behavior of non-U.S. aerospace engineers and scientists in selected countries. Another portion of the project looks specifically at the use of electronic networks by U.S. aerospace engineers (*74*).

Over the long term, the project findings will provides an empirical basis for understanding the aerospace knowledge diffusion process itself and its implications at the individual, organizational, national, and international levels. The results of the project should provide useful information to R&D managers, information managers, and others concerned with improving access to, the quality of, and the utilization of federally funded aerospace R&D (*75*, p. 223). Selected descriptive results from this research, as it pertains to the information-seeking behavior of aerospace engineers, are reported in this section.

Patterns of Technical Communication

The communication of technical information (e.g., producing written materials or oral discussions) is an important aspect of aerospace engineering. Based on a 40-hour week, aerospace engineers spend an average ($\bar{X}$) of 8.7 hours per week writing technical information and 10.3 hours per week communicating technical information orally. Combining these means shows that aerospace engineers spend an average of 19 hours per week communicating in written and oral form. On average, aerospace engineers spend more time per week communicating technical information ($\bar{X}$ = 19.06) to others than they do working with technical information received from others ($\bar{X}$ = 14.64). As their years of work experience increase and as they advance professionally, so too does the amount of time they spend communicating (i.e., producing and using) technical information.

On average, the majority of aerospace engineers prepare written technical communications alone. Of the approximately 22% who write with a group of engineers, about 40% write with the same group of engineers. The average size ($\bar{X}$) of the group is 5.75 people. Of those who write in or with a group, about 22% indicated that doing so made them more productive than writing alone, and 21% indicated that doing so made them less productive than writing alone. Letters and memos were the technical

information products most frequently prepared alone. Drawings/specifications were the technical information product most frequently prepared in a group. Drawings/specifications were the most frequently used technical information product.

Patterns of Technical Information Use and Problem Solving

Aerospace engineers use a variety of technical information sources when solving technical problems. In general, aerospace engineers are not interested in guides to the literature nearly so much as they are interested in reliable answers to specific questions. They prefer informal sources of information, especially conversations with individuals within their organization. Aerospace engineers may also have psychological traits that predispose them to solve problems alone or with the help of colleagues rather than seeking answers in the literature. When they use libraries, they tend to use them in a self-help mode. When they use them, aerospace engineers tend to turn to librarians and library services for assistance only after they have consulted their personal store of information, talked to co-workers and colleagues, consulted a "key" person, and used a library in a personal search mode. Having failed to that point, aerospace engineers search or have a database searched and/or seek the assistance of a librarian or technical information specialist.

The Role of the Library

Regardless of their relative position in the problem solving process, libraries and librarians provide an important link in the aerospace engineer's quest for information. Overall, libraries and technical information centers are important ($\overline{X}$ = 3.8 with 5 being most important) to aerospace engineers in performing their professional duties. Statistically, academically-affiliated aerospace engineers assign a higher rating of importance to libraries and technical information centers than do their counterparts in government and industry. Academically-affiliated aerospace engineers also tend to use libraries and technical information centers more often than do government- and industry-affiliated aerospace engineers.

Why do aerospace engineers not use libraries and technical information centers? The primary reasons include "no information needs" and "information needs met some other way." There also appears to be a positive correlation between "use" by aerospace engineers and "physical distance." In other words, the closer the aerospace engineer resides to the library, the greater the probable use of the library or technical information center.

Factors Affecting Use of Technical Information

The relevant literature overwhelmingly favors accessibility as the single most important (variable) determinant of use. Gerstberger and Allen reported that among R&D engineers, accessibility rather than technical quality influences use (*71*, pp. 279). Allen (*44*) stated, "There is apparently some relationship between the perceptions of technical quality and channel accessibility, but it is the accessibility

component that almost exclusively determines frequency of use" (*44*, p. 185). Rosenberg in a study of research and non-research personnel in industry and government found that both groups exhibited similar information-seeking behavior. Of the eight variable investigated by Rosenberg, both groups indicated that accessibility had the greatest influence on information use (*72*, p. 125). Orr, on the other hand, disagreed, stating that quality of information was the most important consideration in selecting/using an information product (*66*, pp. 146–147). Our results indicate that accessibility influences the use of information products by aerospace engineers. However, accessibility does not "exclusively" determine information use. Relevance and technical quality, together with accessibility, are the factors that affect the use of information products by aerospace engineers.

Use of Information Technology

In Shuchman's investigation (*60*) of information transfer in engineering, aeronautical engineers made greater use of information technologies, including computers, than did engineers in other disciplines (see *76*, *77* for an overview of recent literature on the use of information technology in aerospace engineering). Study data indicate that aerospace engineers tend to use many forms of information technology and that they are likely to use information if accessible via a computer. Approximately half of all aerospace engineers have access to and use electronic networks. Electronic networks are used by aerospace engineers for various purposes including online database searching; communicating via electronic mail, bulletin boards or conferencing systems; logging into remote computers to run programs; and exchanging data and other files.

The Need for Theory-Based Practice

With its contribution to trade, its coupling with national security, and its symbolism of U.S. technological strength, the U.S. aerospace industry holds a unique position in the nation's industrial structure. However, this industry, in particular the commercial aviation sector, is in the midst of profound change and now faces a significantly more challenging competitive and global environment. To remain a world leader in aerospace, the U.S. must improve and maintain the professional competency of its engineers and scientists, increase the R&D knowledge base, improve productivity, and maximize the integration of recent technological developments into the R&D process. How well these objectives are met, and at what cost, depends on a variety of factors, but largely on the ability of U.S. aerospace engineers and scientists to acquire and process the results of aerospace R&D. Hence, an understanding of the information-seeking behavior of aerospace engineers would offer valuable insight for maintaining U.S. supremacy in aerospace.

Despite the expenditure of considerable effort, there is no generally accepted or systematically acquired body of research that can accurately describe or explain information-seeking behavior or predict the use of information by engineers in general and aerospace engineers in particular other than at the most elementary

levels. A variety of environmental and structural changes, including the growth of computer and information technology, combine to significantly weaken the relevance and reliability of this research. Hence there is the need for a modestly constructed engineering-oriented research agenda.

Engineering Information-Seeking Behavior: Developing a Research Agenda

Considerable research and numerous user studies have been conducted over the past 25 years. The generally held beliefs are that (1) the results of this research and these studies have not accumulated to form a significant body of knowledge that can be used by information professionals and (2) the results that are usable have been virtually ignored by those concerned with the design and provision of information policy, products, services, and systems.

An acquired body of research is vital to the development of theory and the solution of professional problems, to the formation of tools and methods for analyzing organizations, services, environments, and behaviors, to determining the cost and benefits of information products, services, and systems, to establishing and developing theories upon which to base practice, and to contributing paradigms, models, and radically new conceptualizations of information-seeking behavior. The following outline suggests the directions that continued research should take.

1. Previous research regarding the information-seeking behavior of engineers is noncumulative, has been variously criticized, and has largely been dismissed on the basis of research and scholarship.
   A. Conduct a "critical" review, analysis, and evaluation of previous research, identify and remove spurious research findings, and establish a starting point or foundation for "what is known and accepted as fact" vis-a-vis engineering information-seeking behavior.
   B. Identify the criticisms and deficiencies of previously used research designs and methodologies and compile a list of "lessons learned" to guard against committing the same or similar mistakes.
   C. Consider the lessons learned in the context of existing research designs and methodologies and identify those that correct or compensate for previous mistakes.
2. Previous research regarding the information-seeking behavior of the engineer has been limited to a particular system, product, or service in a particular organization or environment. Hence, the results are often confusing, conflicting, and not sufficient to form the basis for the development of theory.
   A. Develop standard definitions, terms, and terminologies.
   B. Develop, test, and validate research tools, instruments, and techniques.
   C. Develop a standard set of variables.
      1. Types of Users
         a. Engineers
         b. Scientists
         c. Intermediaries
         d. Gatekeepers
         e. Managers
      2. Types of Organizations
         a. Academic

b. Government
c. Industry
3. Size of Organization
a. Small
b. Medium
c. Large
4. Types of Environment
a. Research
b. Development
c. Design
d. Manufacturing
e. Production
f. Test and Evaluation
g. Marketing and Sales
h. Service and Maintenance
i. Management
5. Types of Knowledge
a. Tacit knowledge
b. Information
c. Data
6. Types of Product/Service
a. Print
b. Nonprint
c. Electronic
7. Types of Engineering Discipline
a. Civil
b. Electrical
c. Mechanical

D. Determine which variable(s) (institutional and situational) best describe and explain the use of information by engineers in a variety of environments.

3. What is known about the information-seeking behavior of engineers seems not to explain information use and nonuse. Hence, there is little knowledge that can be used for testing existing and developing new paradigms.
   A. Conduct engineering information-seeking behavior research within a conceptual framework that embraces the production, transfer, use, and management of information. One possible outcome could be the identification of barriers that prohibit or restrict the use of information by engineers.
   B. Seek to understand the diffusion of engineering knowledge as a precursor to describing and explaining the information-seeking behavior of engineers.
   C. Develop and test hypotheses, the results of which, can lead to the formation of theory that can be used to predict the use of information by engineers.
   D. Develop a series of experiments, the results of which will lead to the formation of paradigms, models, and radically new conceptualizations of library and information science phenomena.
4. Conventional wisdom states that a "disconnect" exists between researchers and practitioners in the field of library and information science.
   A. Develop a mechanism that couples the results of basic and applied research with users in the field.
   B. Develop the means by which researchers and practitioners have greater opportunities for interaction.

Determining what we know and where we are will provide a starting point to formulate the questions that must be asked. The answers to these questions will form the elements of a basic research program and lead to the development of theory-based

practice. Applied research can then be used to test and validate these theories. Tests and validation will lead to the identification of spurious findings and eventually to the accumulation of a significant body of knowledge that can be used by information professionals to design aerospace information policy, products, services, and systems.

NOTES

1. See Chapter 2, "Technology Policy and the Technology Base" in *Beyond Spinoff: Military and Commercial Technologies in a Changing World*, by John A. Alic et al. for an in-depth discussion of "tacit" knowledge.
2. The *Annual Review of Information Science and Technology* periodically reviews the literature relevant to "Information Needs and Uses." The reviews published to date are listed below:

Vol.	Year	Author	Chapter No. and Title	Pages
1	1966	Herbert Menzel	3–Information Needs and Uses in Science and Technology	41–69
2	1967	Saul & Mary Herner	1–Information Needs and Uses in Science and Technology	1–34
3	1968	William J. Paisley	1–Information Needs and Uses	1–30
4	1969	Thomas J. Allen	1–Information Needs and Uses	1–29
5	1970	Ben-Ami Lipetz	1–Information Needs and Uses	3–32
6	1971	Diana Crane	1–Information Needs and Uses	3–39
7	1972	Nan Lin & William D. Garvey	1–Information Needs and Uses	5–37
9	1974	John Martyn	1–Information Needs and Uses	4–23
13	1978	Susan Crawford	3–Information Needs and Uses	61–81
21	1986	Brenda Dervin Michael Nilan	1–Information Needs and Uses	3–33

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